Heavy Ion Physics in ATLAS:
progress on Pb+Pb analysis
& plans for early p+p data

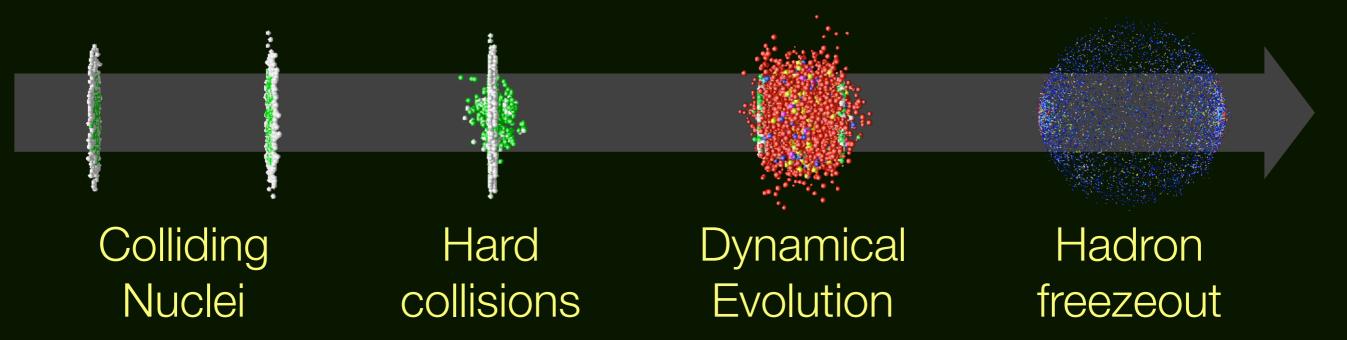
Peter Steinberg

Brookhaven National Laboratory

& the Heavy Ion Working Group

ATLAS Overview Week, July 7-11, 2008, Bern, Switzerland

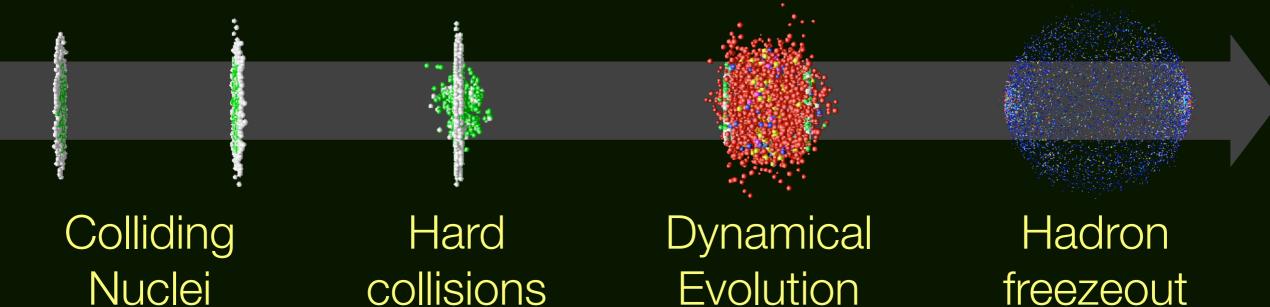
Evolution of a Heavy Ion Collision



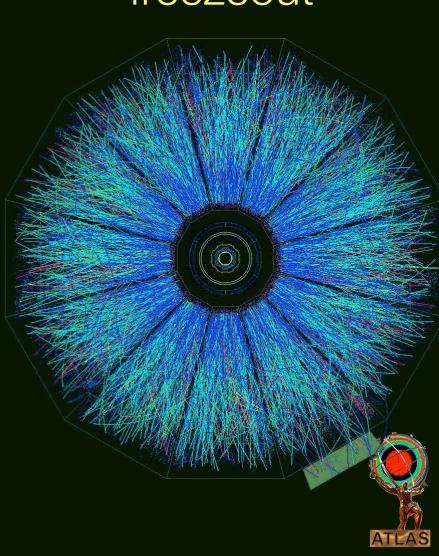
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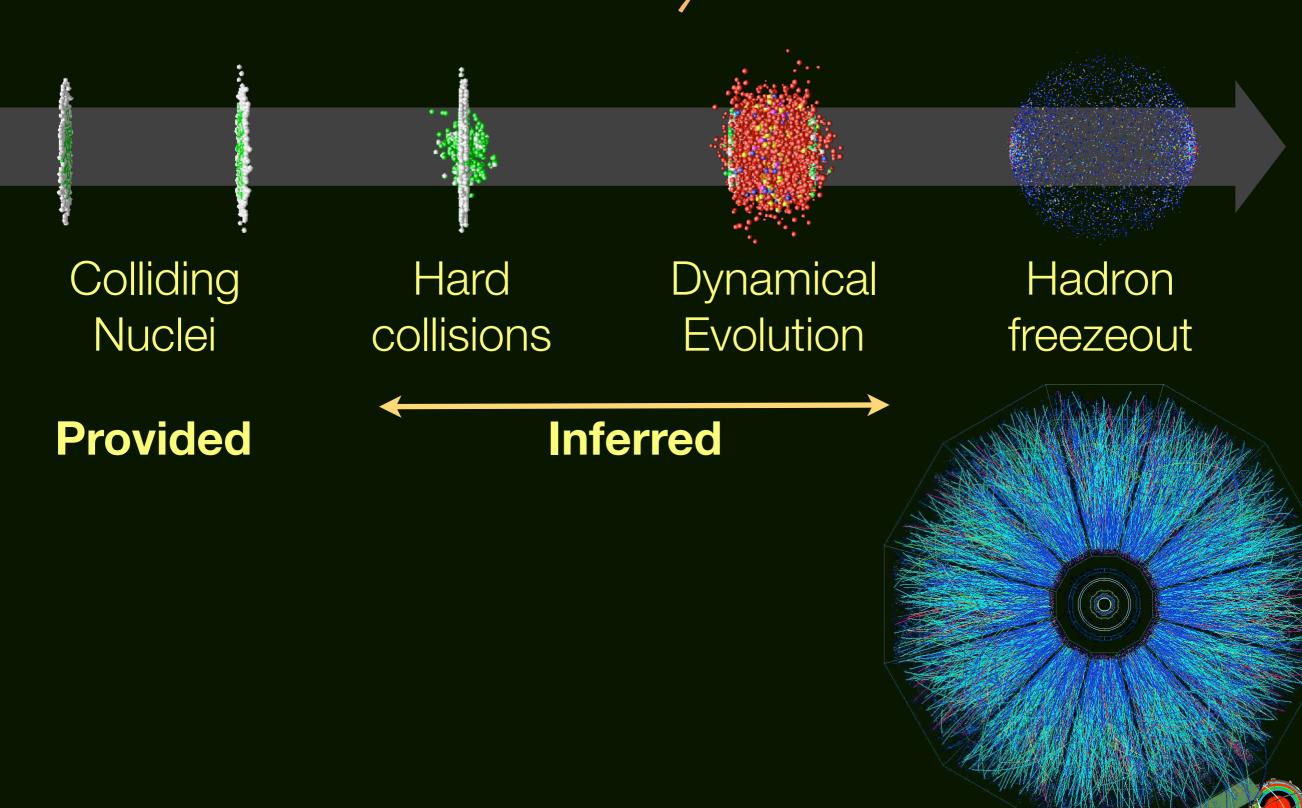
Evolution of a Heavy Ion Collision



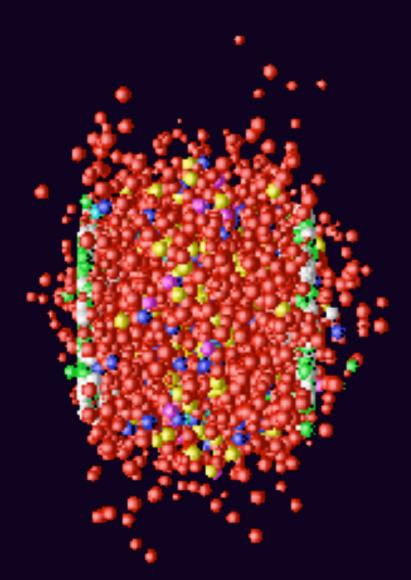
Provided



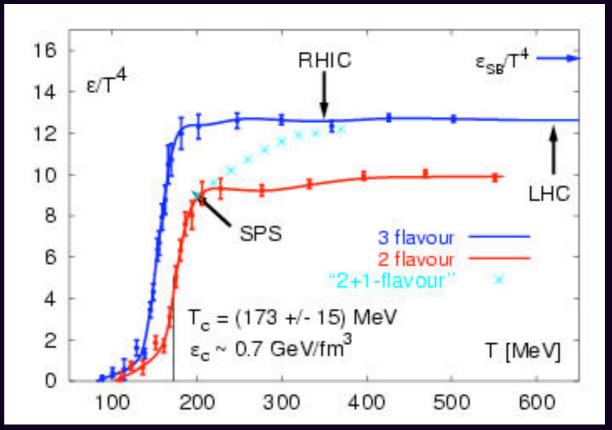
Evolution of a Heavy Ion Collision



The QGP on the Lattice



$$\epsilon = rac{E}{V} \propto n_{d.o.f.} T^4 egin{array}{l} {
m energy} \\ {
m density} \end{array}$$



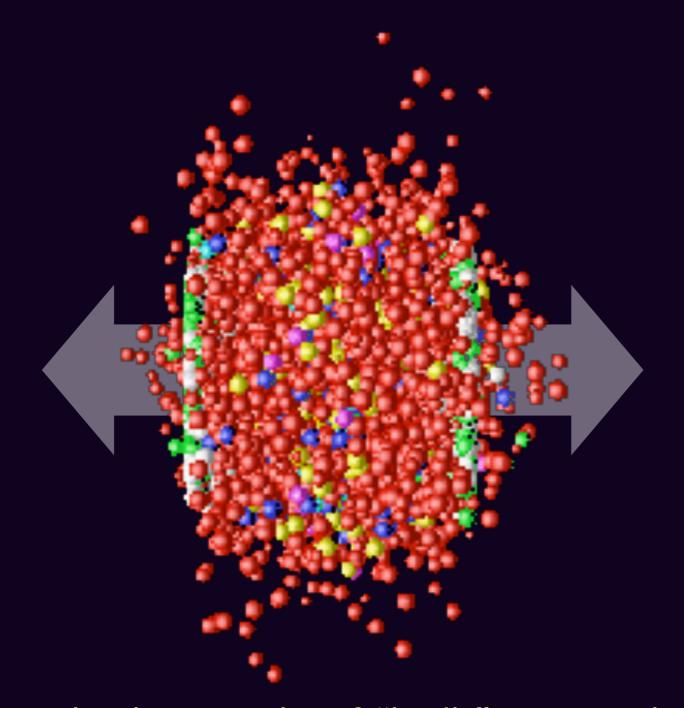
Karsch et al, 2001



"deconfinement" @ Tc



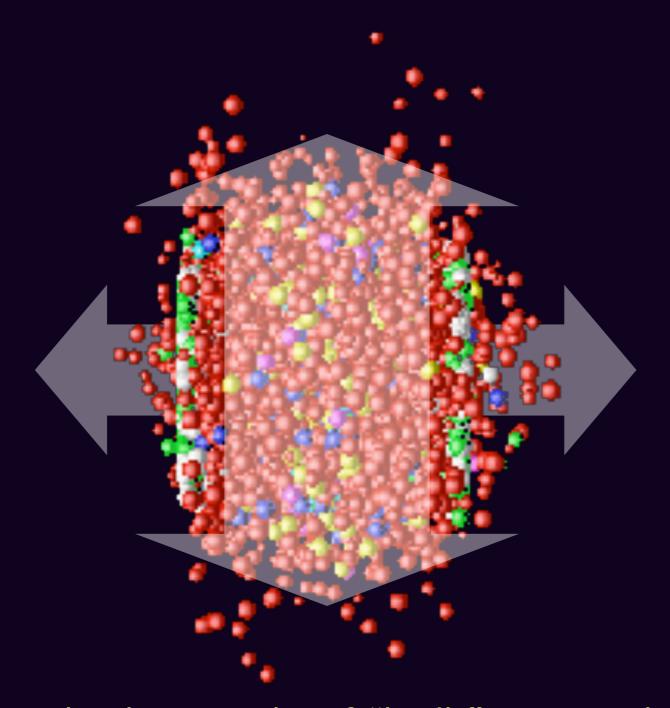
Bulk Evolution



Quantitative study of "bulk" properties: conversion of energy density to entropy, pressure evolves via **hydrodynamic** flow



Bulk Evolution



Quantitative study of "bulk" properties: conversion of energy density to entropy, pressure evolves via **hydrodynamic** flow



Hydrodynamics

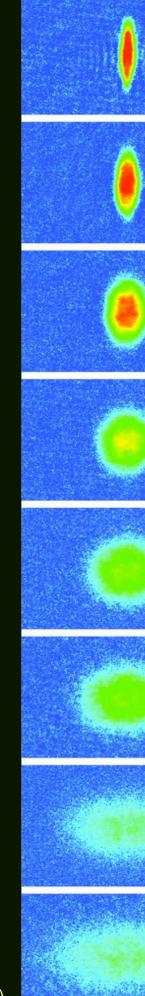
$$T_{\mu\nu} \equiv (\epsilon + p)u_{\mu}u_{\nu} - g_{\mu\nu}p$$
$$\partial_{\mu}T_{\mu\nu} \equiv \frac{\partial T_{\mu\nu}}{\partial x_{\mu}} = 0$$

Hydrodynamic behavior is quite general: simply requires local equilibrium of degrees of freedom → strong coupling

Depends on:

Initial state (geometry, energy density)
Equation of State (EOS), e.g. from lattice
Freezeout criteria

Deviations from ideal hydro also crucial



 $100 \mu s$

200 μs

 $400 \mu s$

600 μs

800 μs

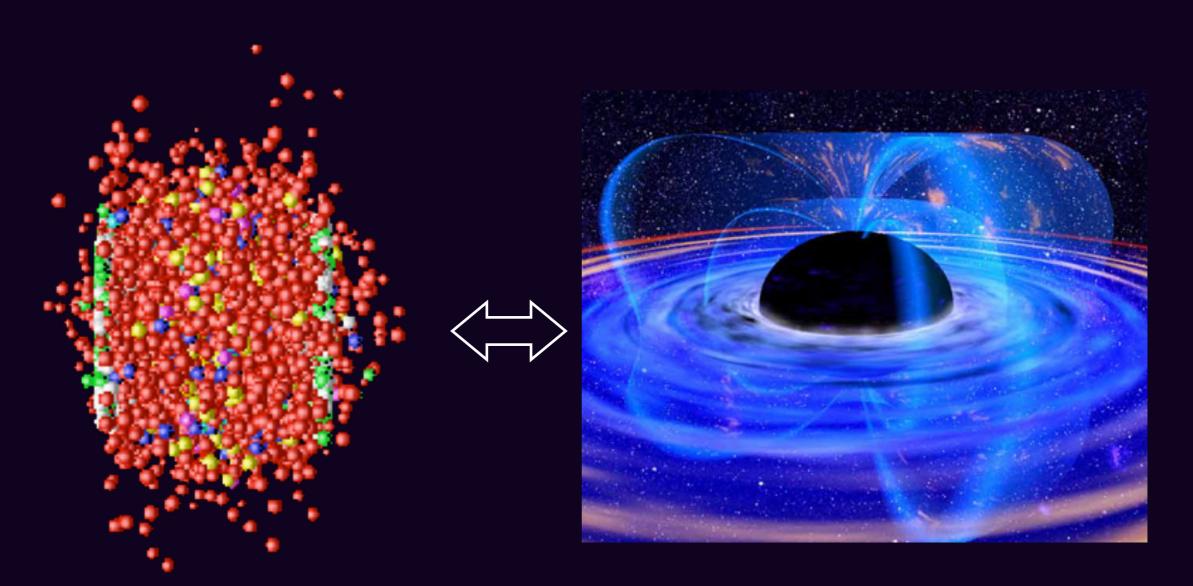
1000 μs

1500 μs

2000 μs

Images from trapped Li⁶ ions at Feshbach resonance (O'Hara et al)

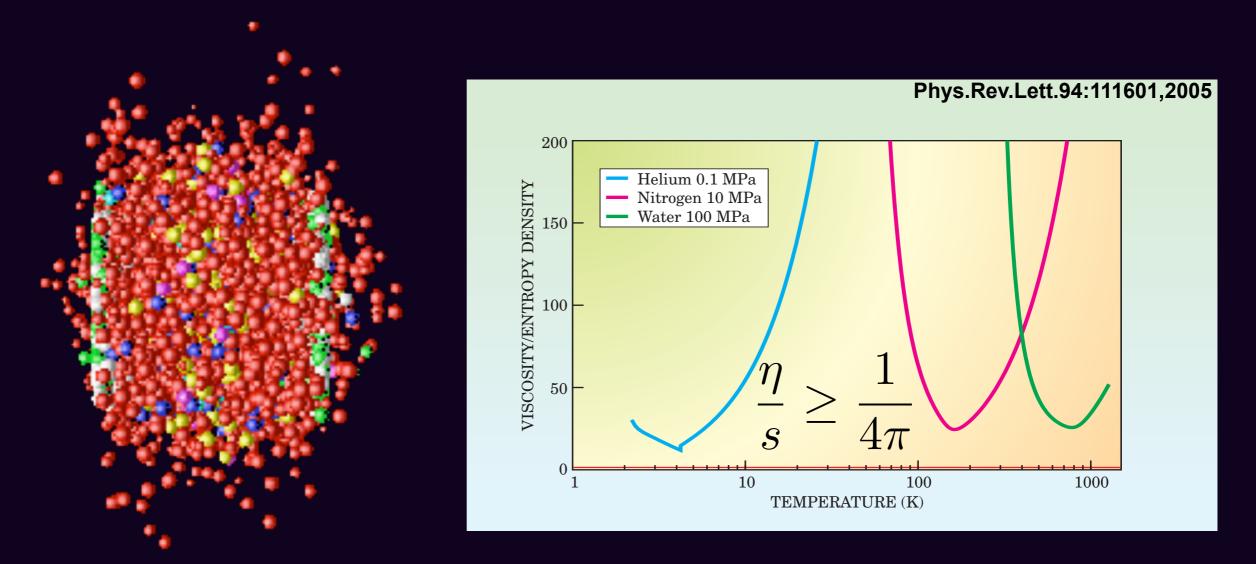
The AdS/CFT connection



Strongly-coupled QGP is thought to be dual to a 10D gravity theory: first experimental connection to string theory



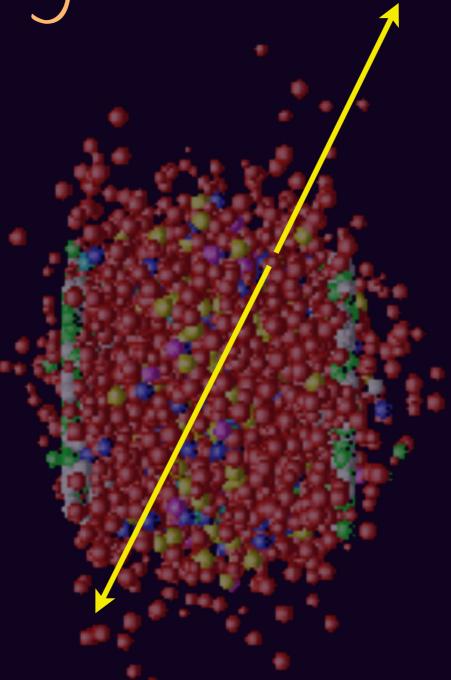
Viscosity Bound from AdS/CFT



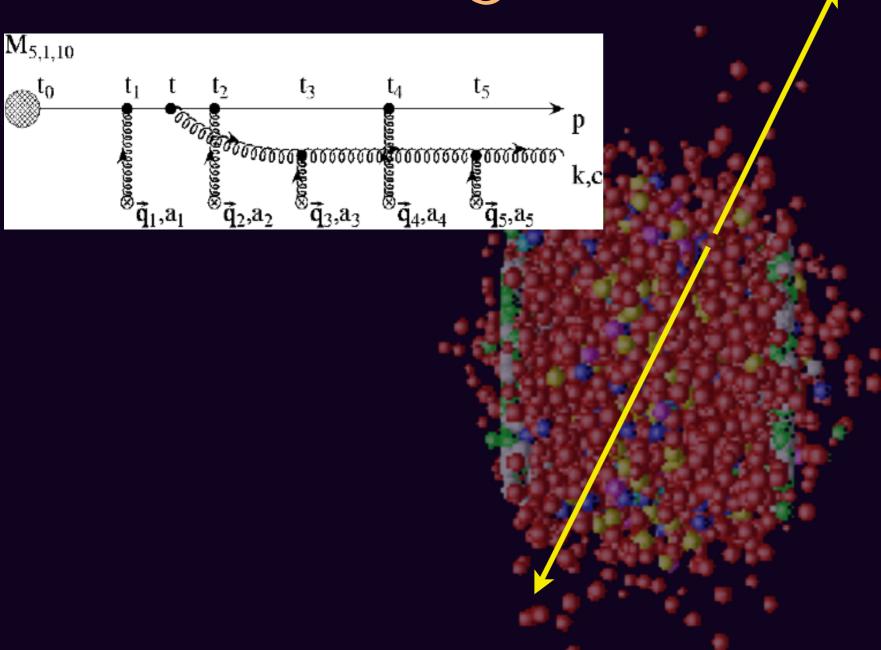
AdS/CFT predicts viscosity of strongly-coupled QGP: deviation from perfect local equilibrium.

Depends on microscopic properties of medium.

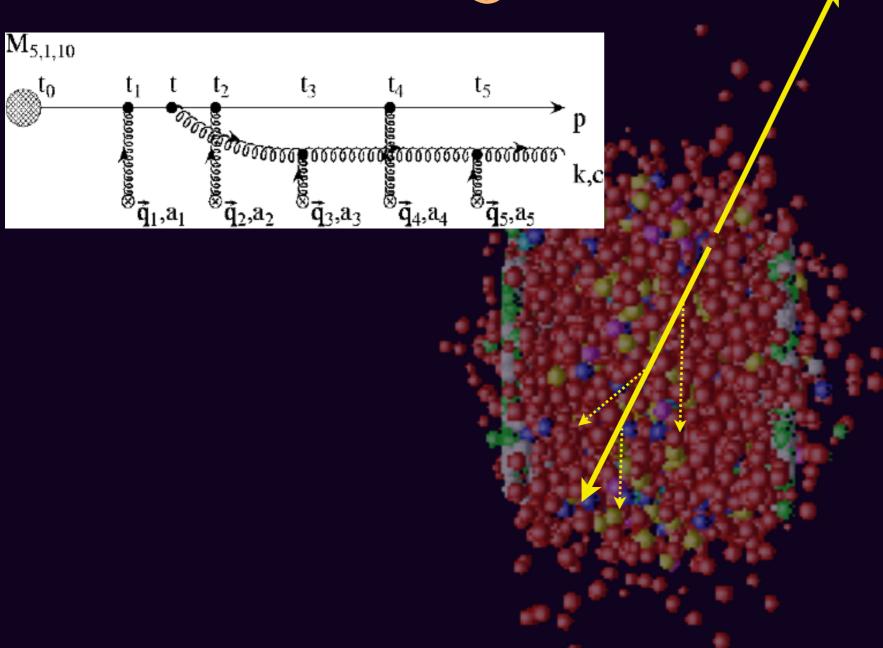




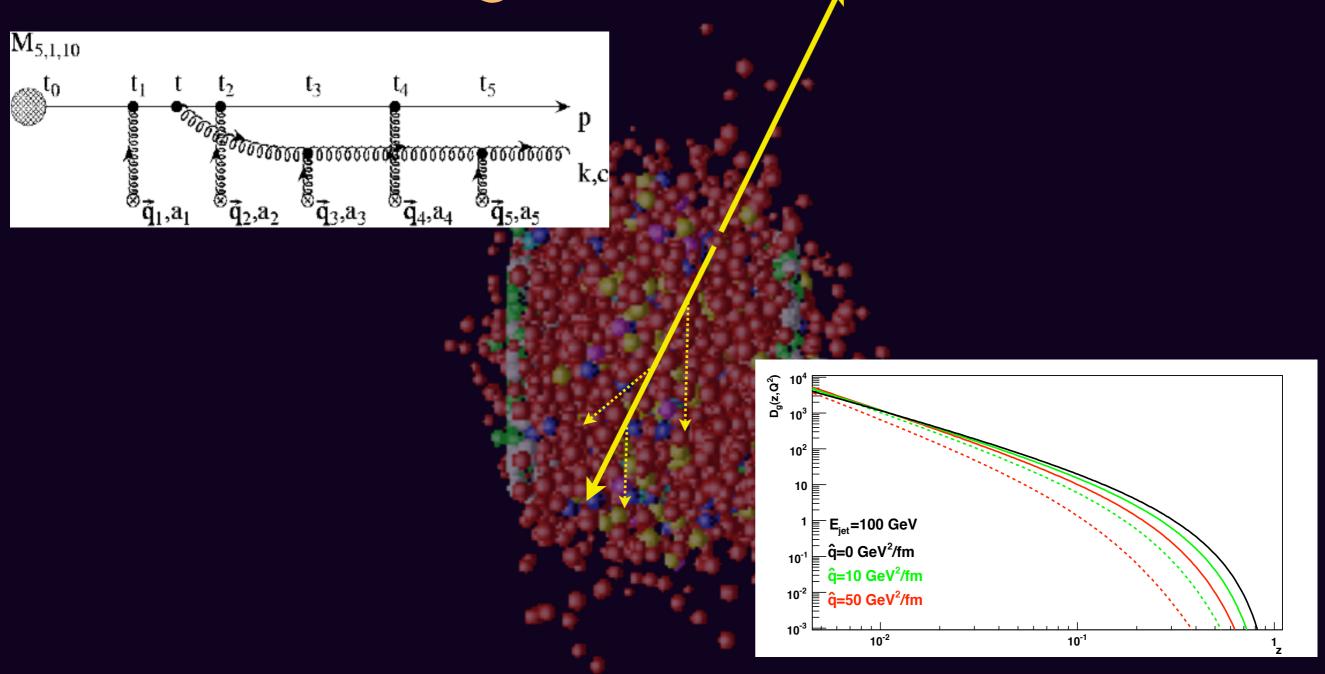






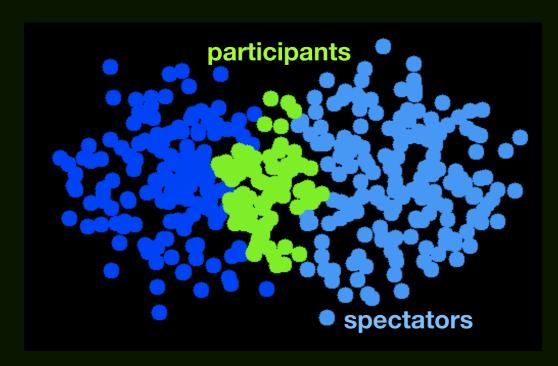






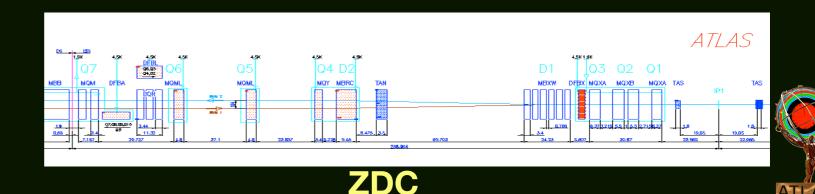


Interlude: The Role of Geometry

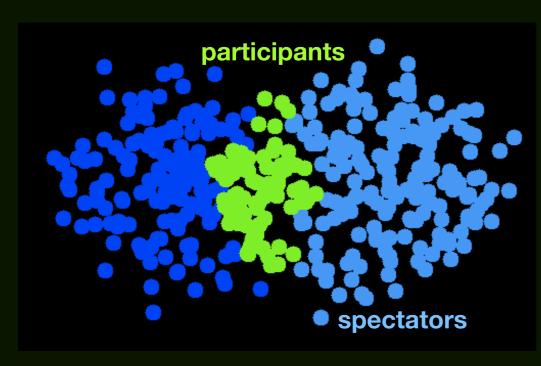


Impact parameter of each collision has strong effect on particle production: number of participating nucleons & their "shape"

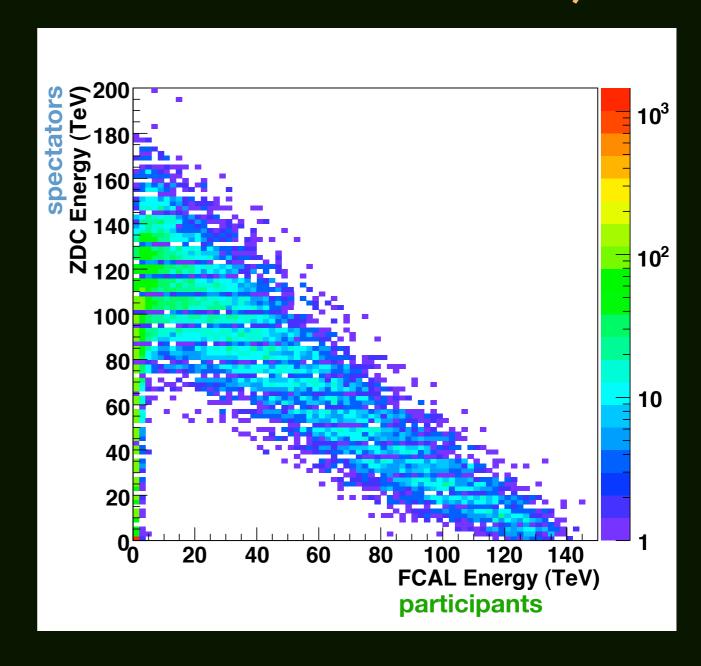
Will be measured event by event, e.g. with ZDC (M. Zeller's talk)



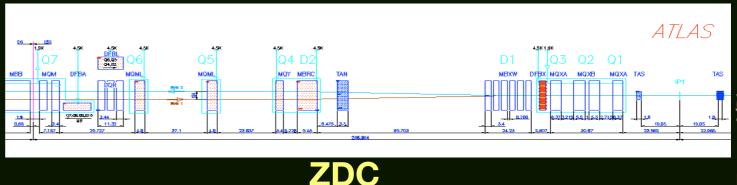
Interlude: The Role of Geometry



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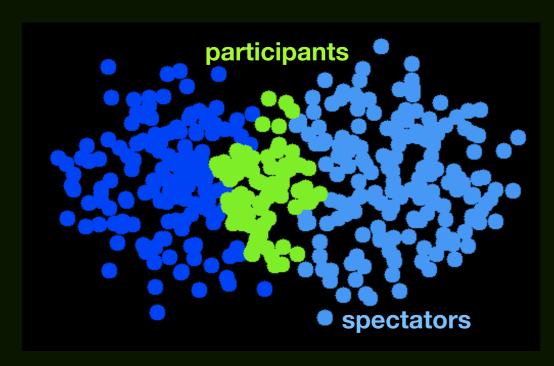


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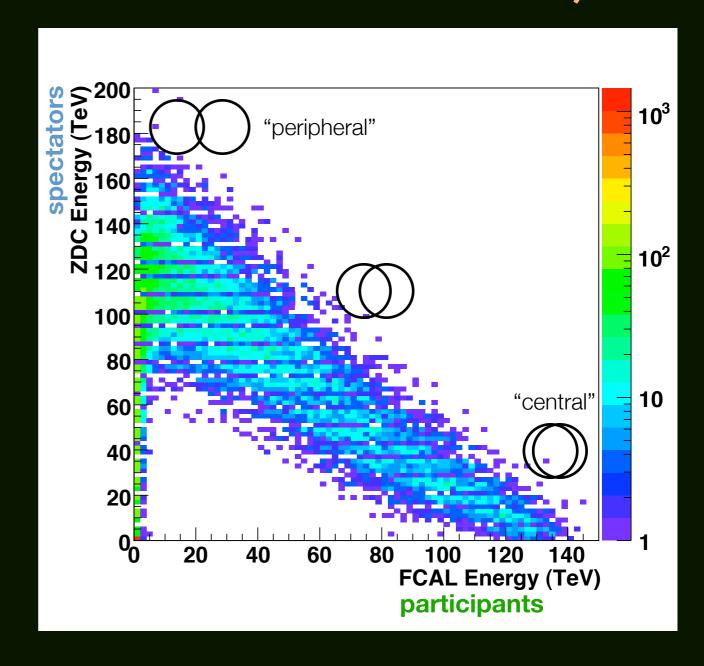




Interlude: The Role of Geometry



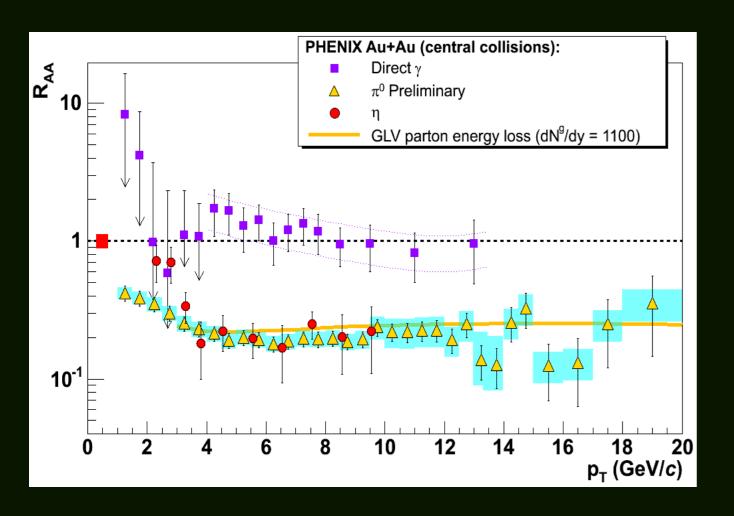
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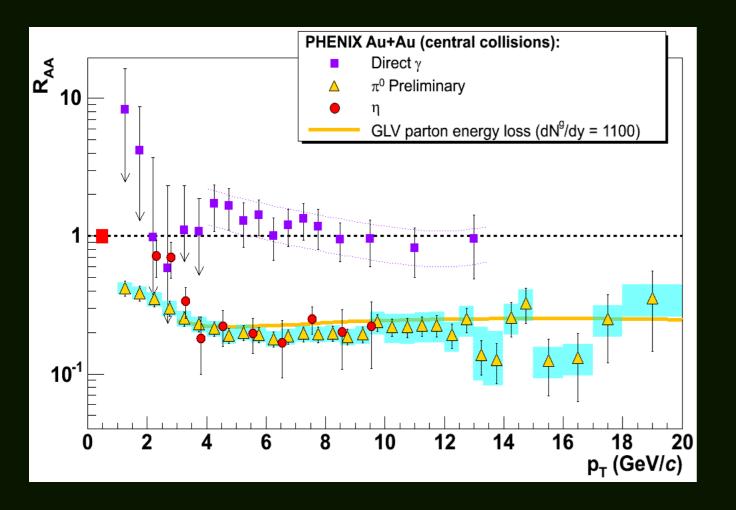
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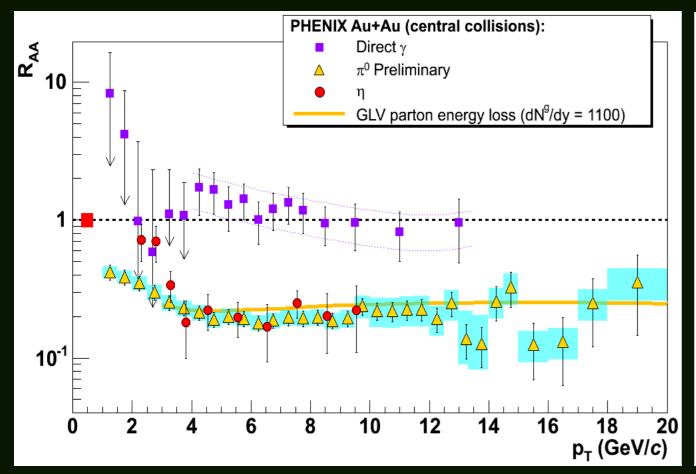


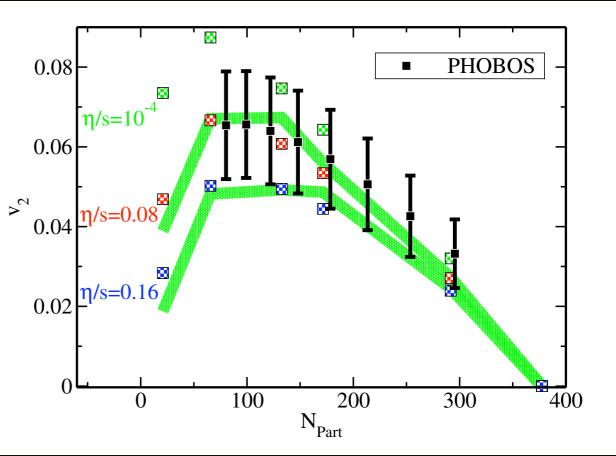


$$R_{AA} = \frac{1}{N_{coll}} \frac{dN/dp_T(Pb+Pb)}{dN/dp_T(p+p)} \label{eq:Raa}$$
 Binary Relative yield collisions





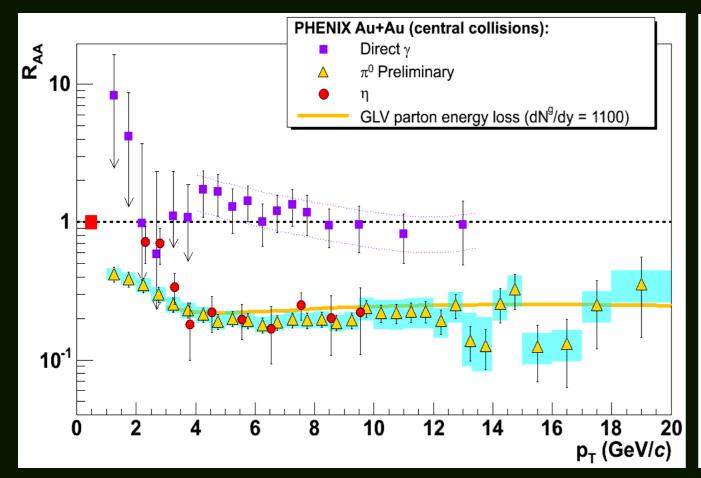


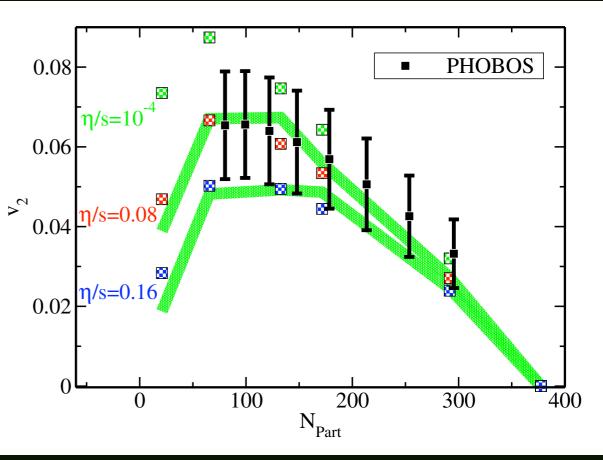


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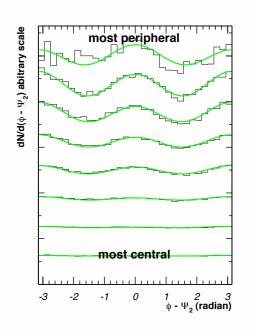




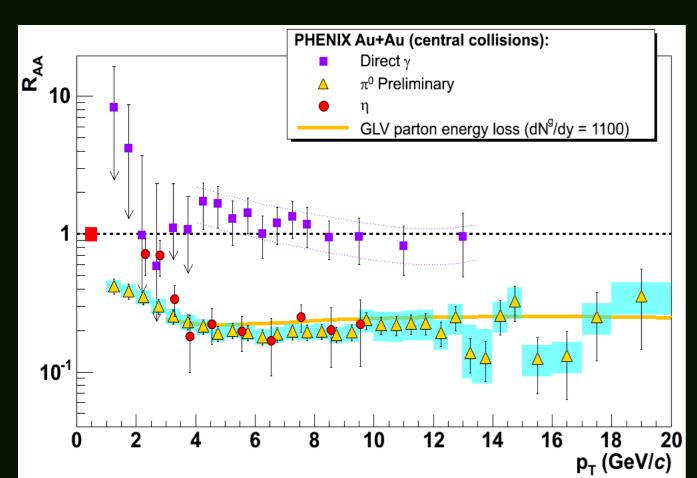
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 Binary Relative yield collisions

Strong elliptic flow, indicating early thermalization (< 0.6 fm/c) and η /s near bound[!]

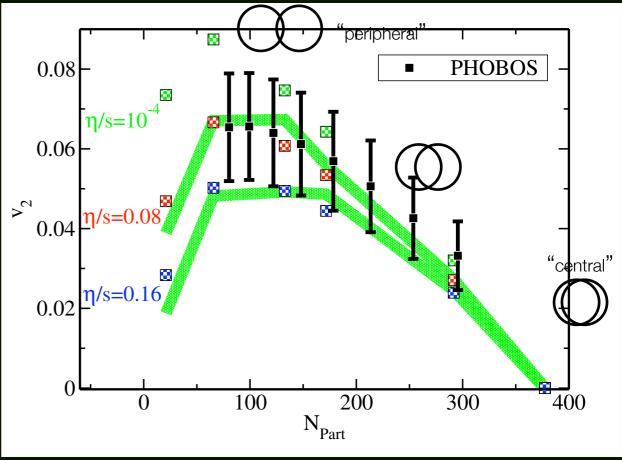
 $v_2 = \langle \cos(2\phi) \rangle$







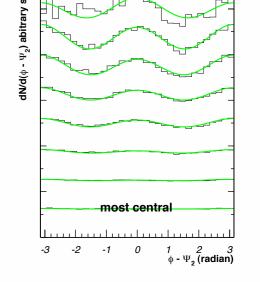




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 Binary Relative yield collisions

Strong elliptic flow, indicating early thermalization (< 0.6 fm/c) and
$$\eta$$
/s near bound[!]

 $v_2 = \langle \cos(2\phi) \rangle$



most peripheral



The Crisis

Hydrodynamics

Models work but no direct observation of primary degrees of freedom

3D viscous hydro only in early stages of development

Poor understanding of initial conditions & controversy over EOS

Jet quenching

Theory is continually challenged by data, e.g. strong suppression of heavy flavor suggests non-perturbative dynamics

Can only study medium if we have a detailed understanding of how the primary hard scattered partons are affected by it

Early thermalization

What is the system made of, and how and when does it thermalize and achieve such low viscosity?



Heavy Ion Physics: The Collider Era



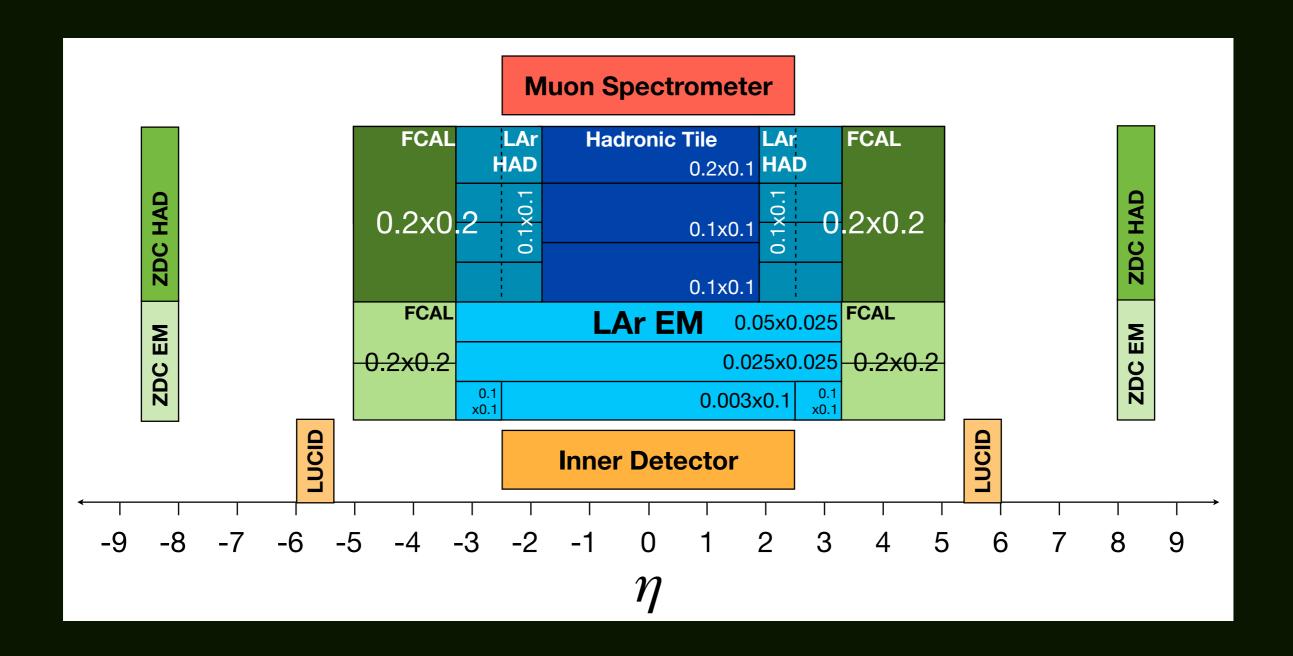
Luminosity frontier

Energy frontier

RHIC and LHC programs are complementary places to study the strongly-coupled medium: LHC is the place for truly high p_T jets and photons



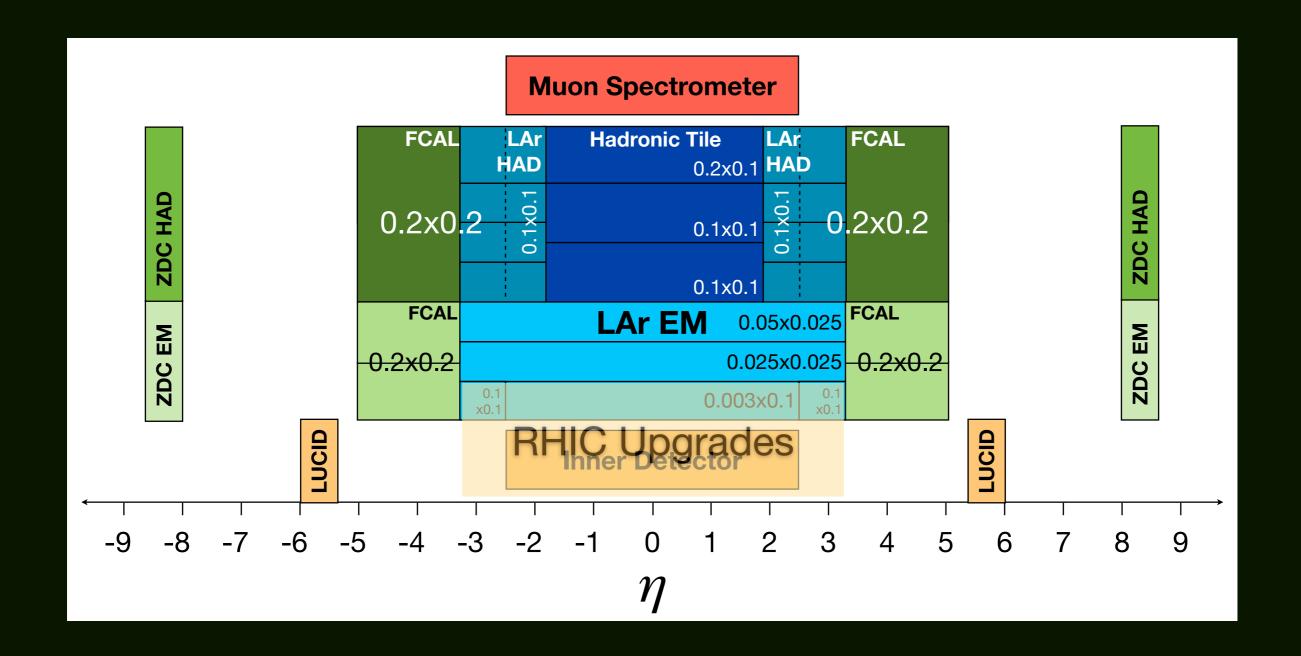
The LHC & ATLAS



ATLAS acceptance unprecedented for HI ATLAS Calorimetry far beyond anything at RHIC & LHC



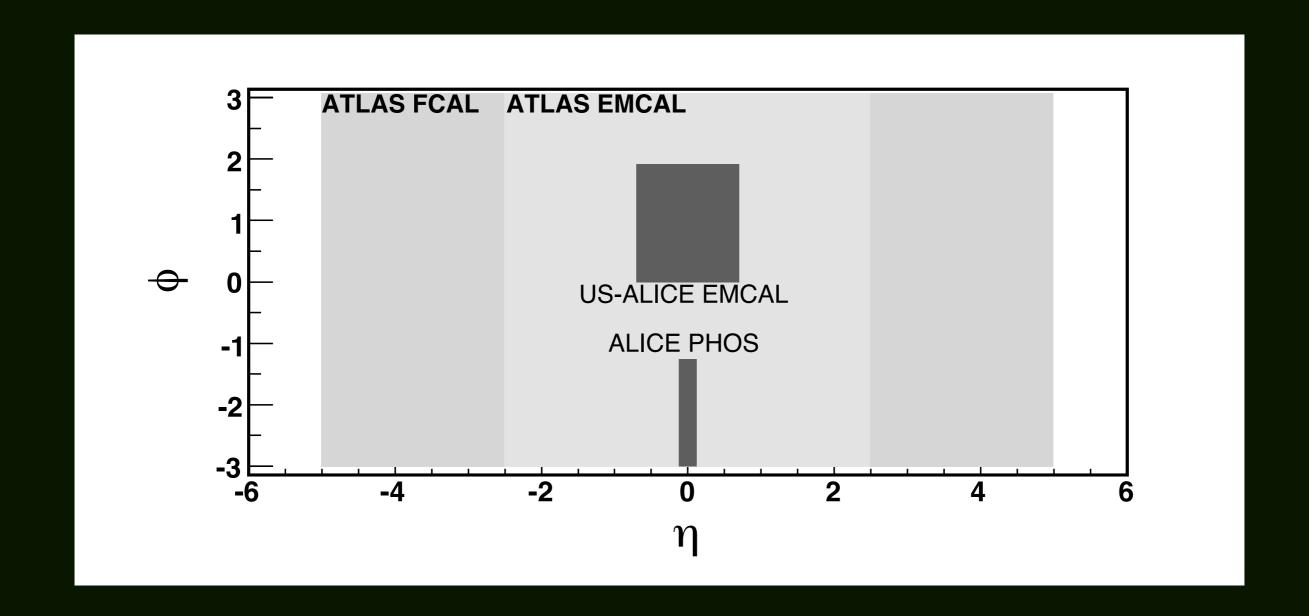
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Calorimetry: ATLAS VS. ALICE



ATLAS calorimeter dramatically exceeds ALICE capabilities for jets & photons



Progress Towards P6+P6

- LHC is essential for continued progress in the study of QGP properties, via bulk observables and especially high p_T proceses
- ATLAS HI Working Group will cover all of the important physics topics for Pb+Pb @ the LHC

Global Variables (multipicities, elliptic flow)

Jets (light and heavy flavor)

Photon & Photon-Jet

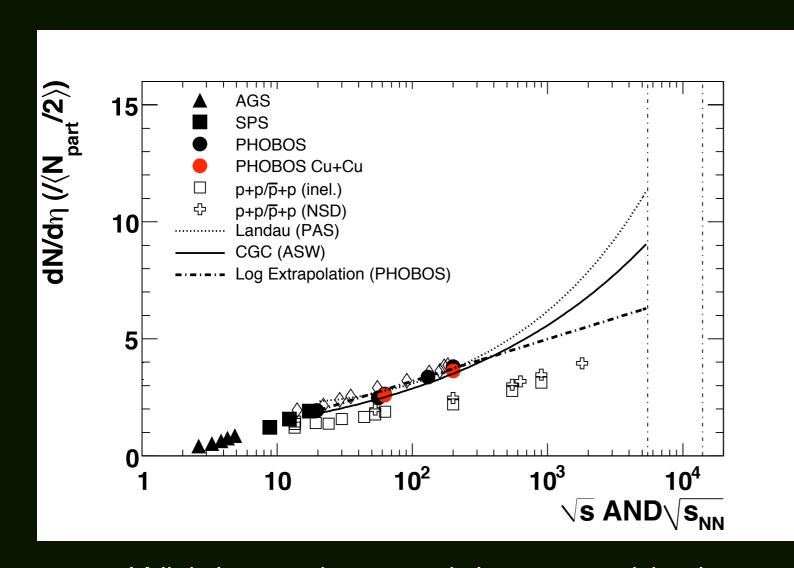
Quarkonia (progress on J/ψ , Υ - not shown today)

Ultraperipheral collisions (using ZDC)

Enormous progress since Stockholm

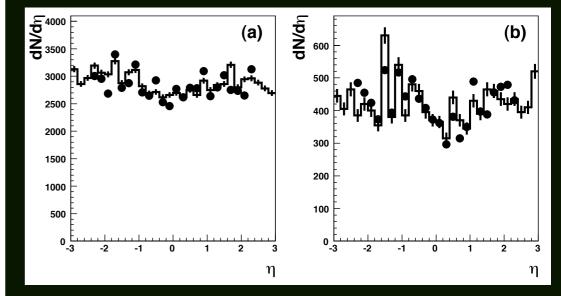


Global: Particle Multiplicity



Widely varying models or empirical extrapolations of particle production developed with RHIC data:

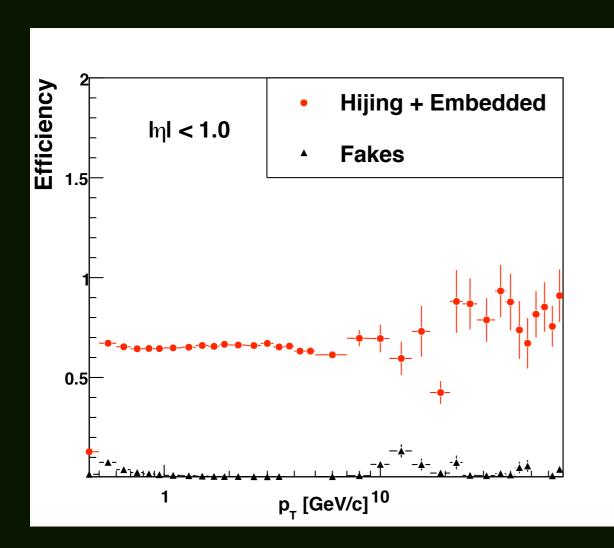
LHC finally allows tests

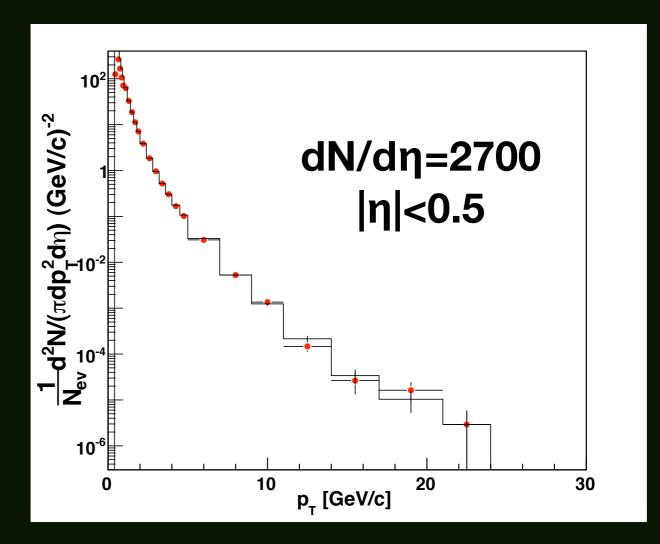


Using various pixel layers, can measure dN_{ch}/d**η** event-by-event



Charged Particle Spectra

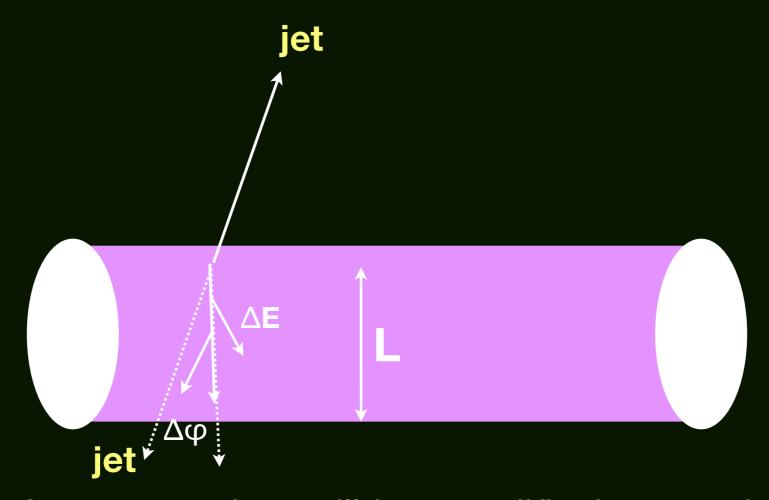




Even in high multiplicity background of heavy ion collision, tracking efficiency & fake rate under control (xKalman)

Expect good first measurement of particle spectra out to >20 GeV (with a few hours of data!)

Measuring Jets in P6+P6

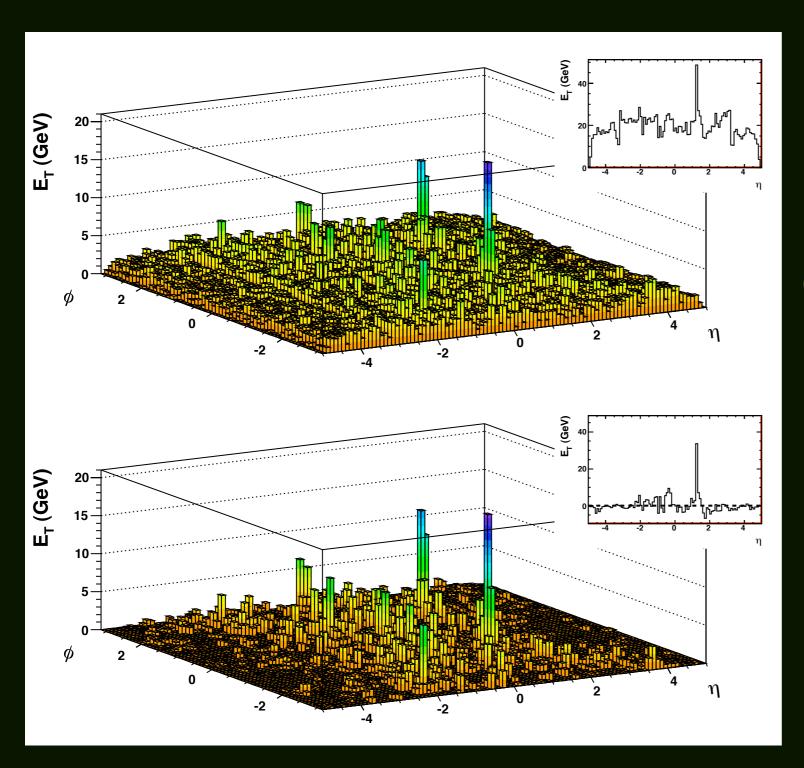


Jet fragmentation will be modified as each jet passes through length L of medium

Don't expect too much energy outside nominal jet cone, so merging PYTHIA jets into HIJING backgrounds -- large underlying event (minijet) fluctuations



Jet Finding in P6+P6: Cone Algo



Seeds are towers above a fixed cut (e.g. 5 GeV)

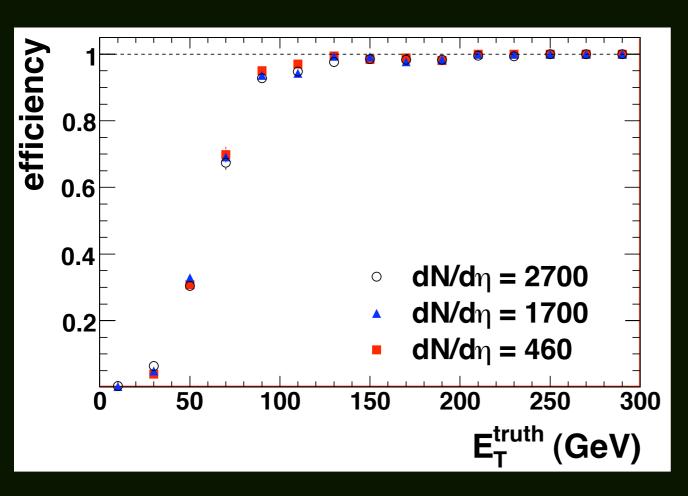
Cell background is calculated as function of η for each layer, excluding regions around seeds

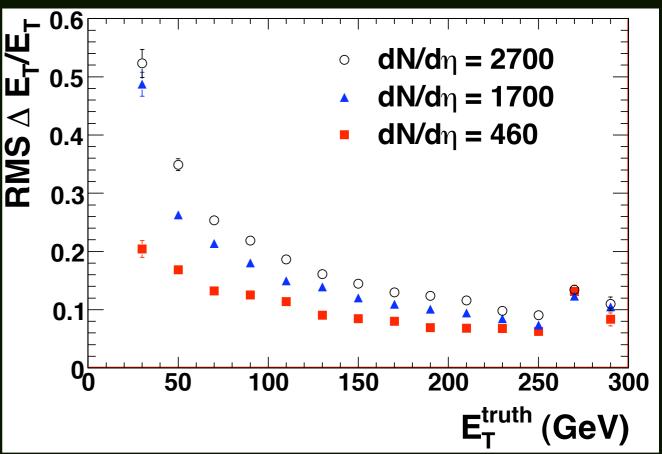
Subtracted before cone algorithms are run with R=0.4

Also running FastJet: results comparable



Jet Efficiency & Resolution



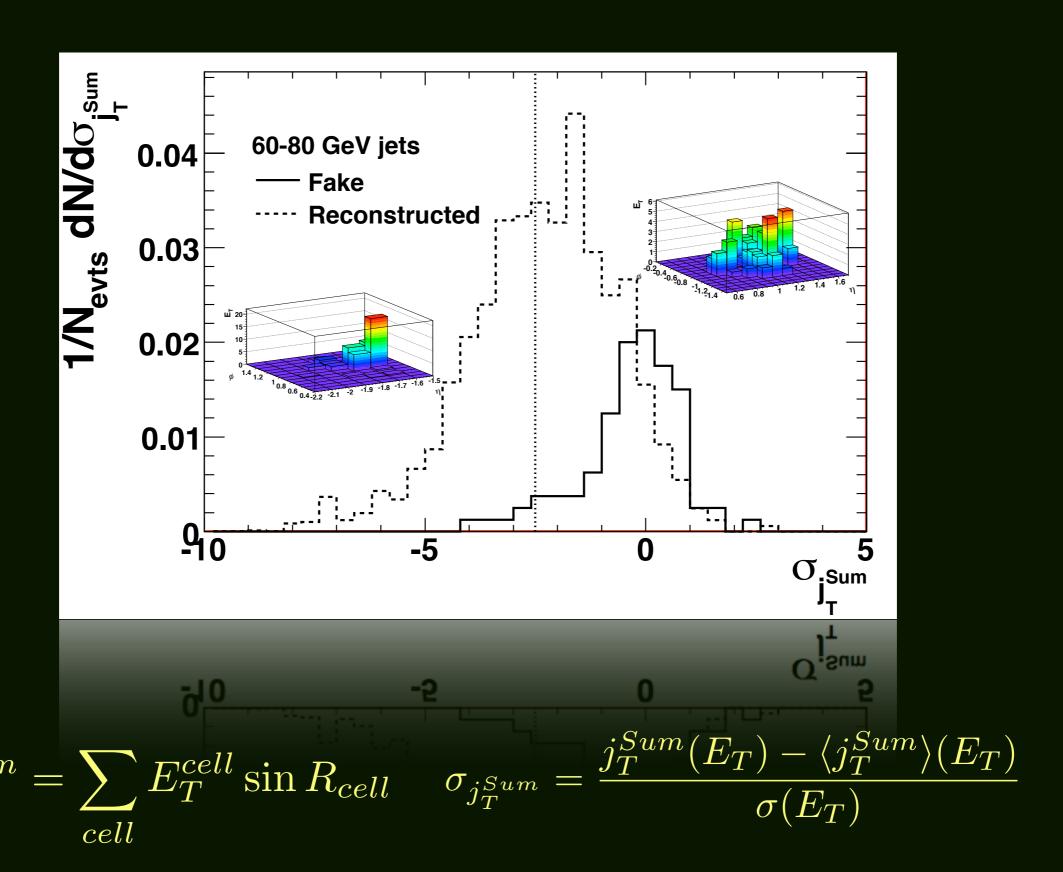


Efficiency rises rapidly above 50 GeV (with current cuts), with little dependence on background level

Resolution is degraded by background fluctuations

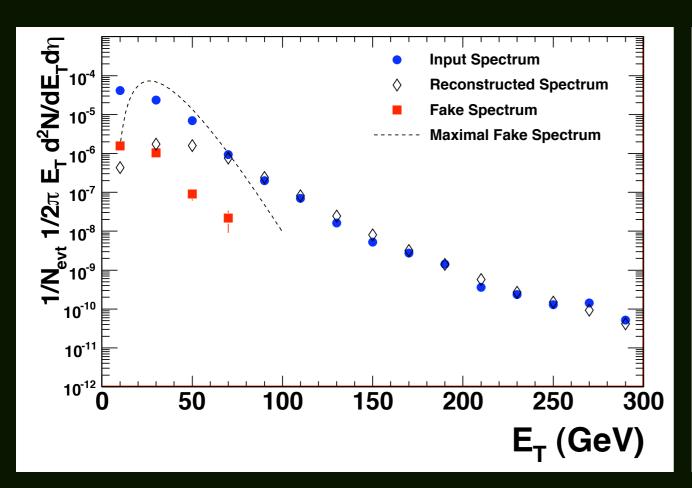


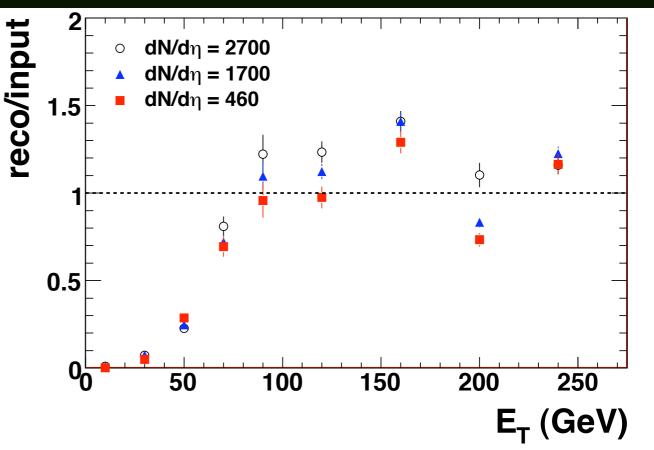
Rejecting Fake Jets in P6+P6





Jet Spectrum



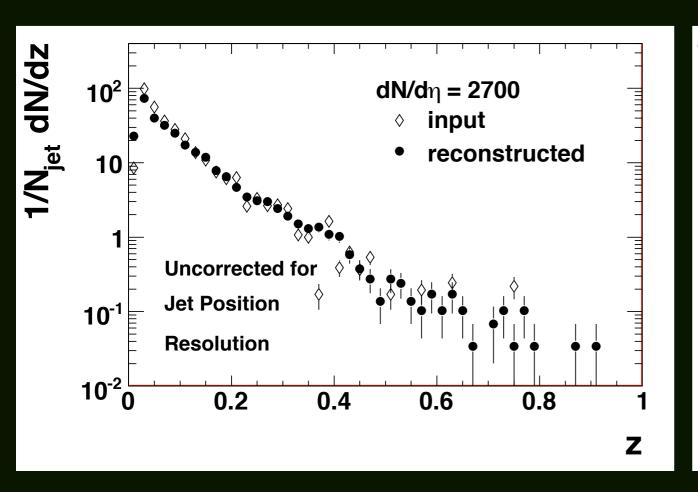


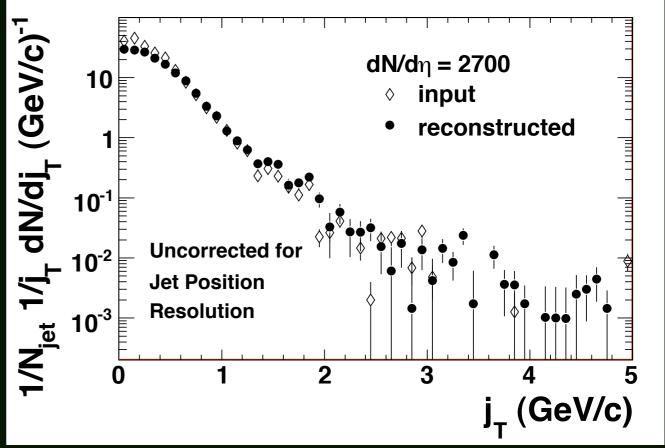
Background fluctuations would overwhelm jets below 80 GeV without jet shape cuts. Biases under study.

Good reconstruction of input spectrum, independent of background level.



Jet Fragmentation



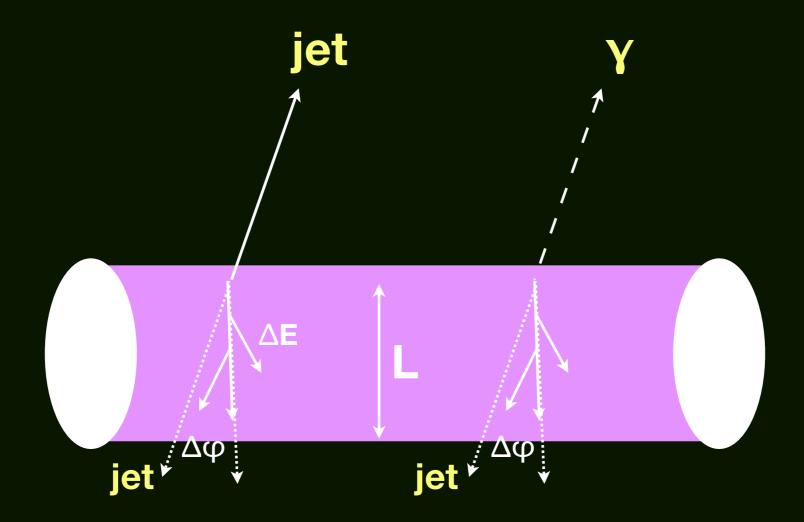


Even in central Pb+Pb, we are able to reconstruct basic properties of jet fragmentation

Essential for study of modified fragmenation



Importance of Photons in P6+P6

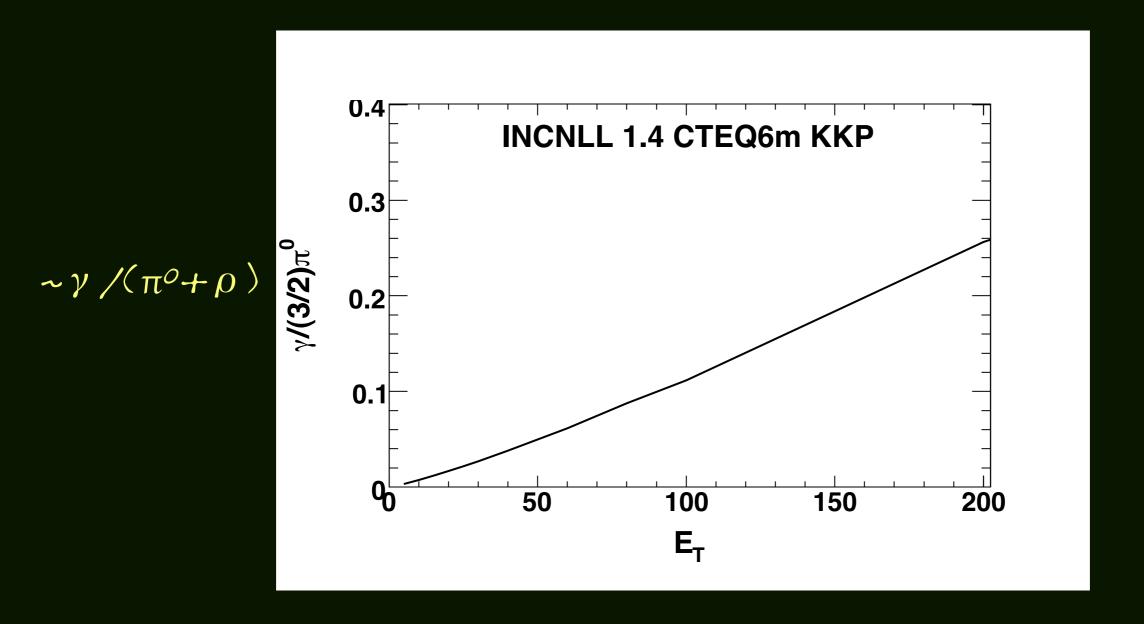


Using y's minimizes trigger bias by tagging the Q² of the primary hard process

Generally thought to be the golden channel to study jet quenching.

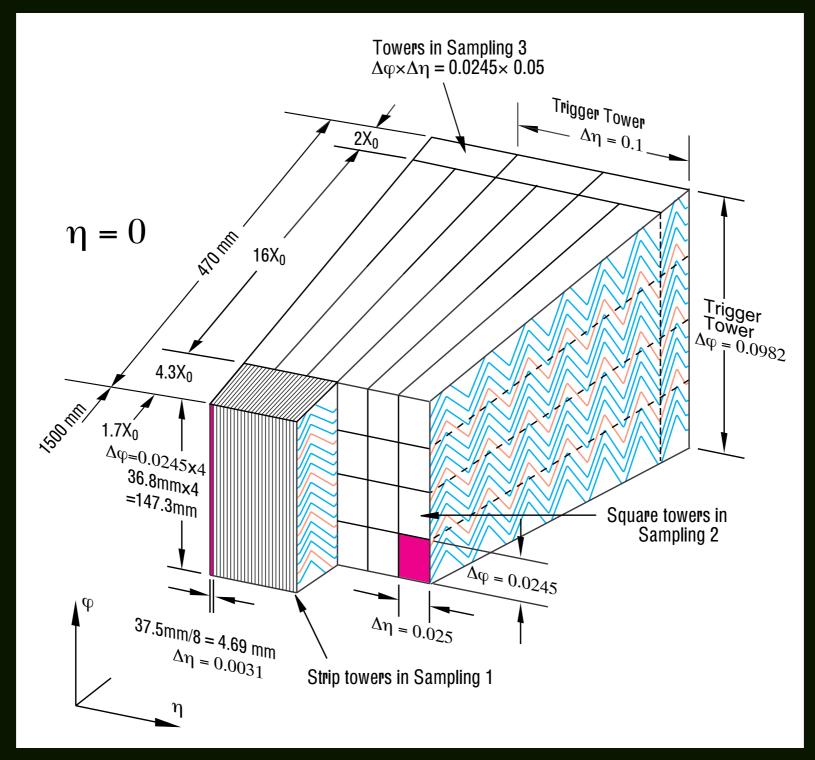


Photon Rates



Even at high p_T, photon spectrum well below neutral hadrons. Rejection power is the relevant figure-of-merit.

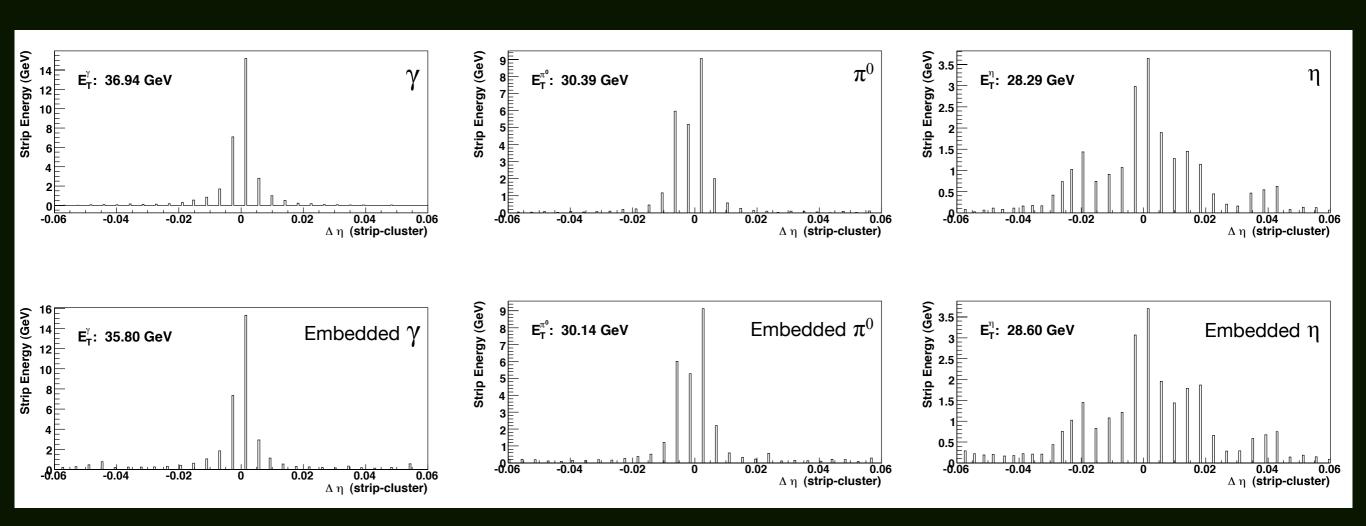
ATLAS Longitudinal Segmentation







Photon Discrimination



Photons show a clear single peak Neutral hadrons (diphoton decay) give wide or double peaks

No effect from embedding in Pb+Pb event

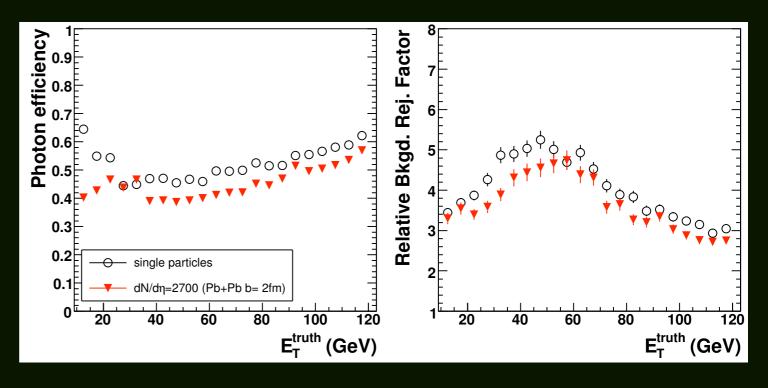


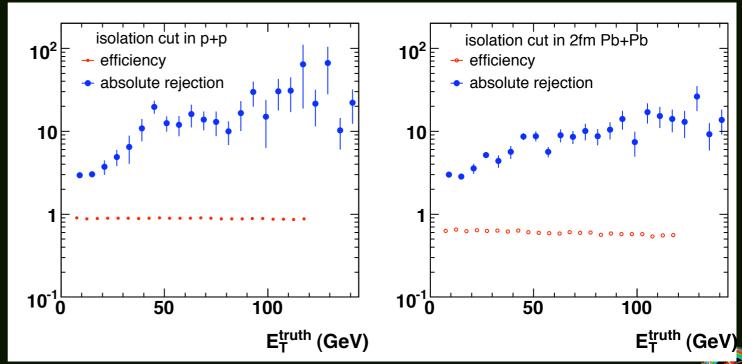
Efficiency & Rejection

Loose & tight cut sets developed (6 variables)

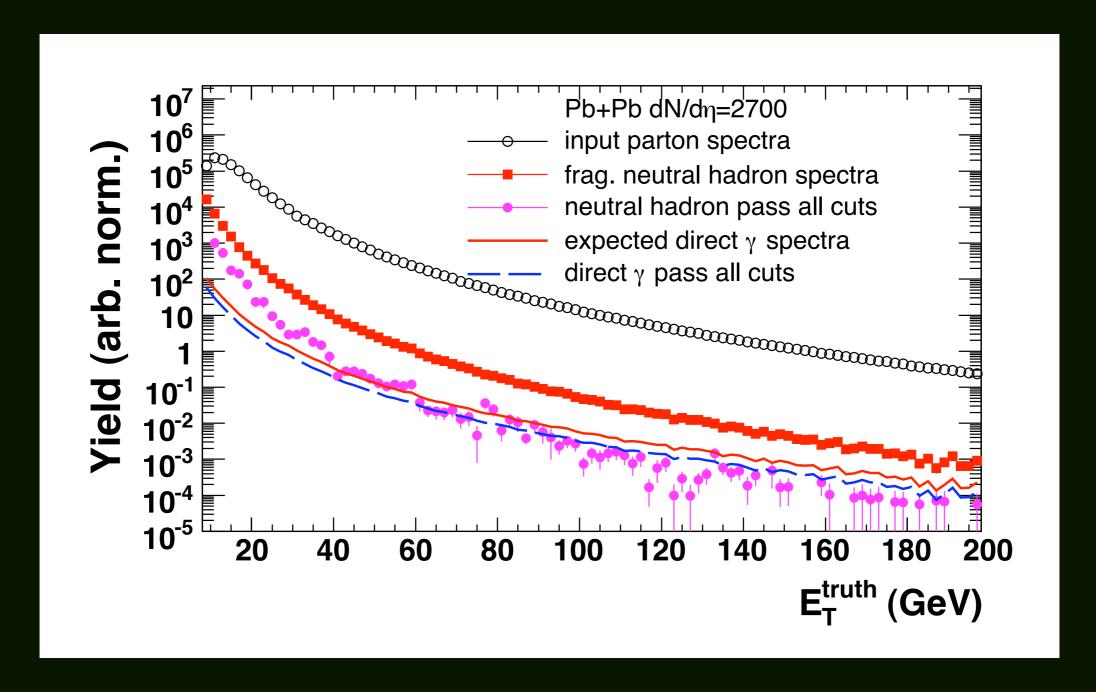
Tight: 50% efficiency, 3-5x rejection just from shower shape

Adding isolation cuts (energy cut in annulus, no track within R<R_{cut}) improves rejection of hadrons by x6-7





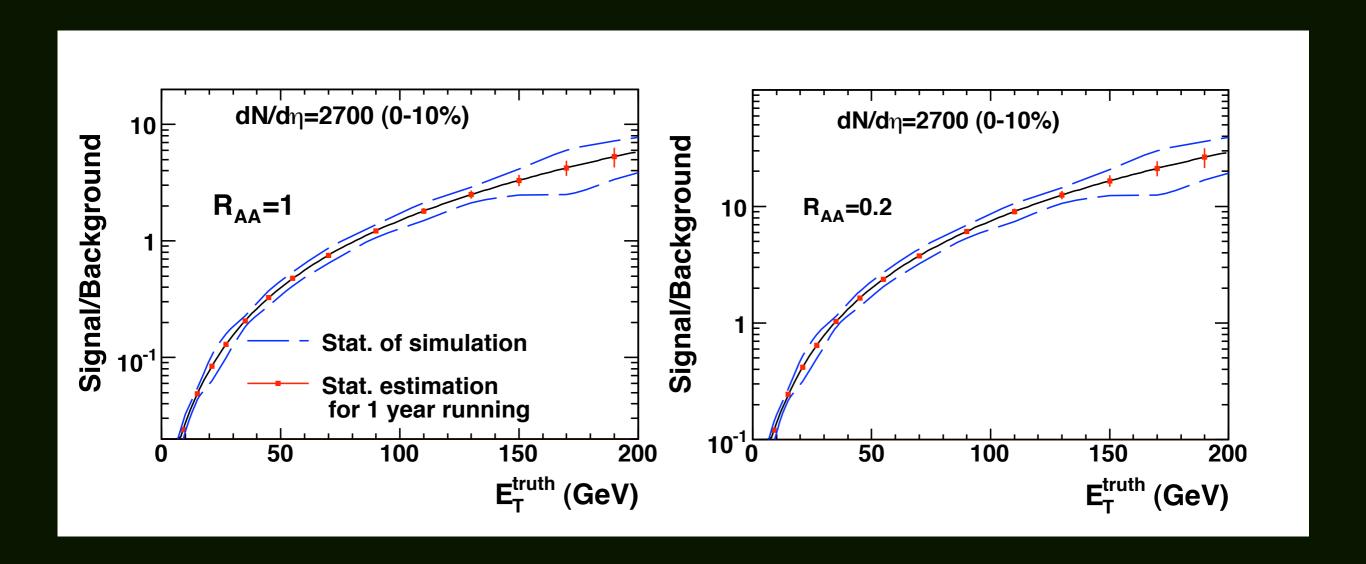
Cutting away backgrounds



Neutral hadrons clearly pushed below photons above ~100 GeV



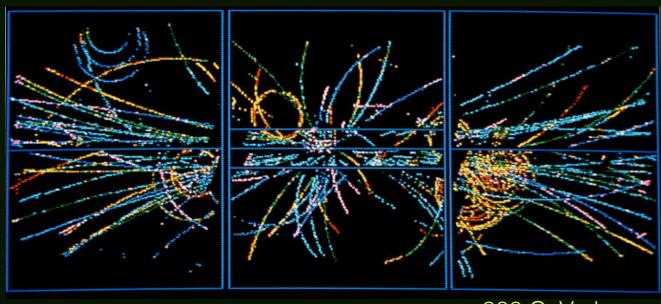
Signal to Background



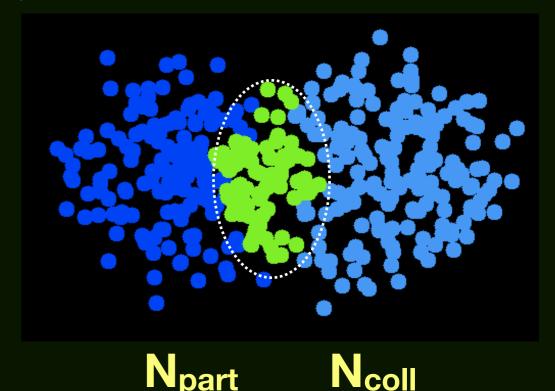
Signal/Background exceeds 1 at 80 GeV assuming no high p_T suppression, 30 GeV assuming RHIC suppression



The importance of p+p data



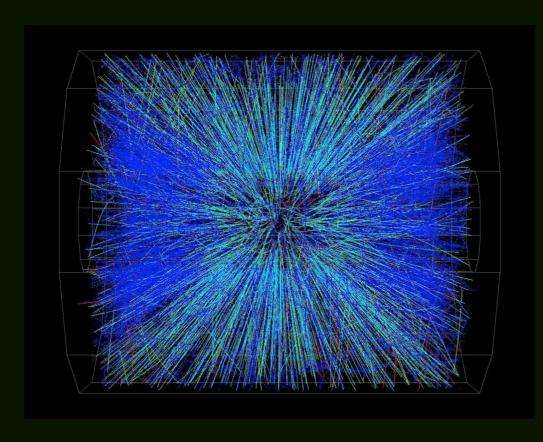




Npart participants

binary collisions

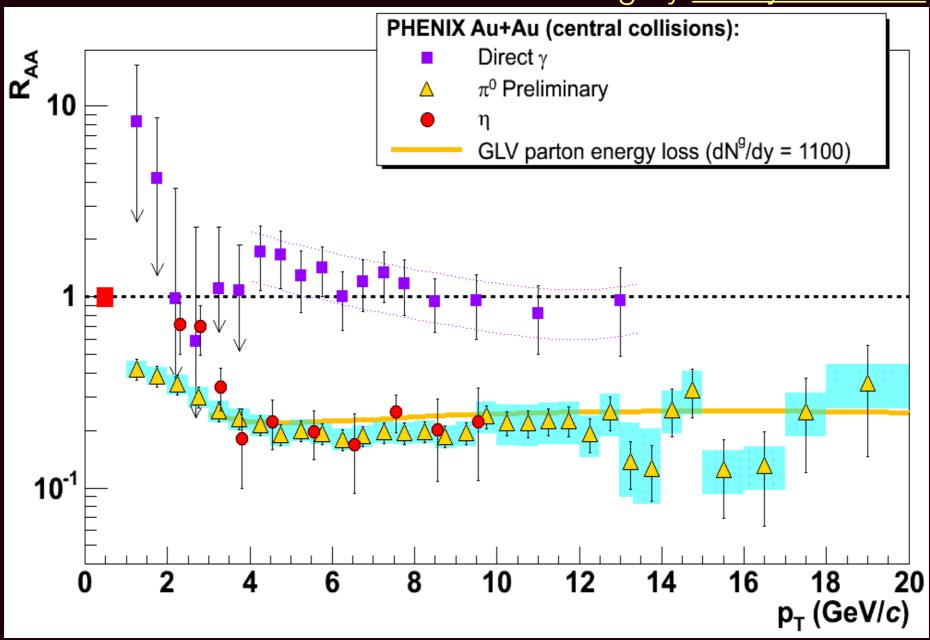




Can we "build" a heavy ion collision from p+p collisions?

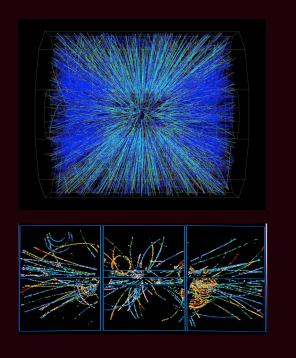


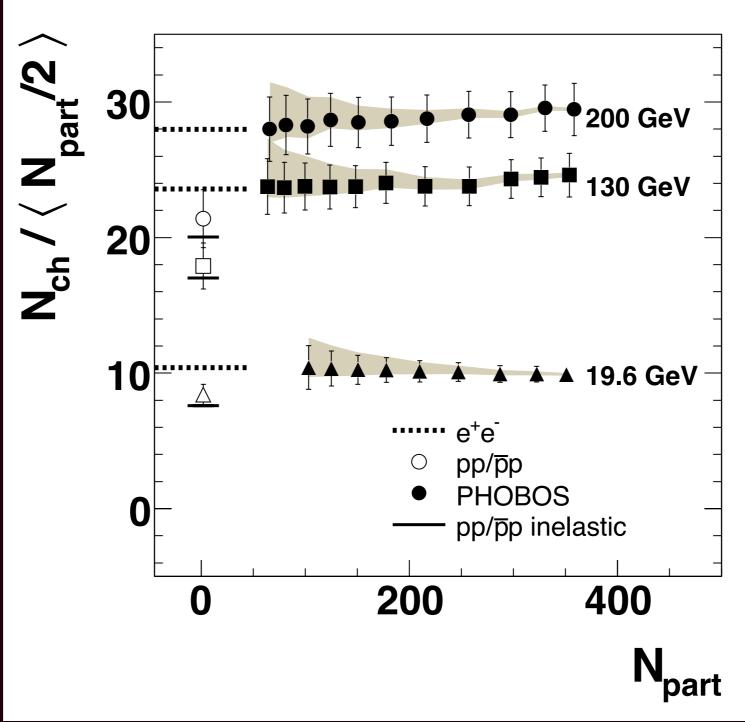
scaling by binary collisions

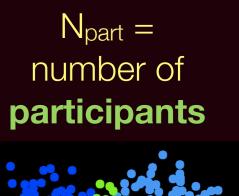


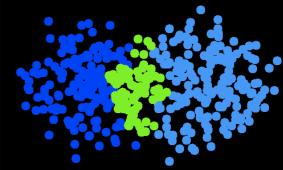
With direct photons, you <u>can</u> with hadrons (jet fragments), you <u>can't</u>

scaling by participant pairs









With inclusive particles (integrated over y & p_T), you <u>can</u> (but A+A is 50% higher than p+p -- leading particle effect)

Heavy Ion Contibutions to ptp

Crucial reference data for Pb+Pb

- Inclusive charged multiplicities, transverse energy
- Hadron spectra (esp. inclusive charged, neutrals)
- Inclusive jets, dijet correlations
- Inclusive photons, photons-jet correlations

Well understood trigger is essential

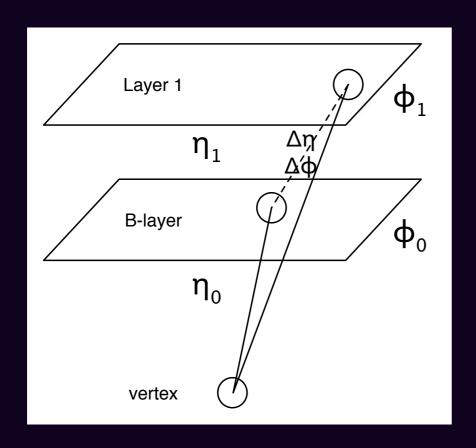
(Truly) minimum bias triggered events, for comparison with soft observables by means of geometric quantities

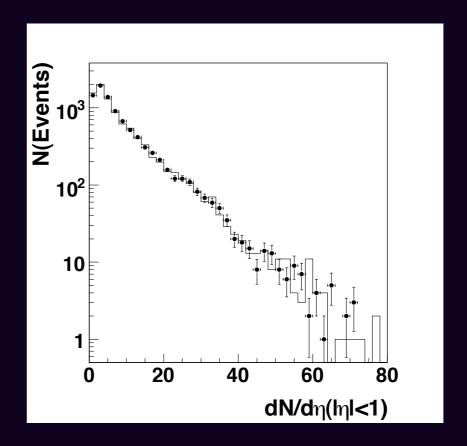
Jet & egamma triggers (which will be modified to account for HI uncorrelated backgrounds)



Contributions to minbias ptp

 Some of us have been contributing to the minbias p+p group since April 2006





 We have been training our algorithms on p+p data in order to compare to Pb+Pb performane

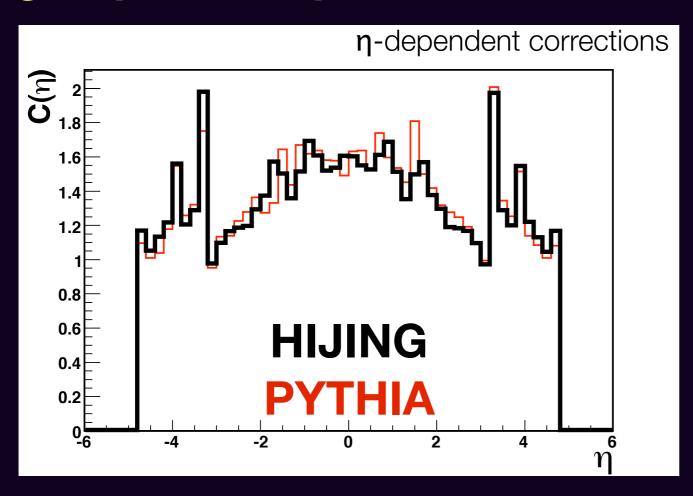
Expect to test our techniques on jets and photons

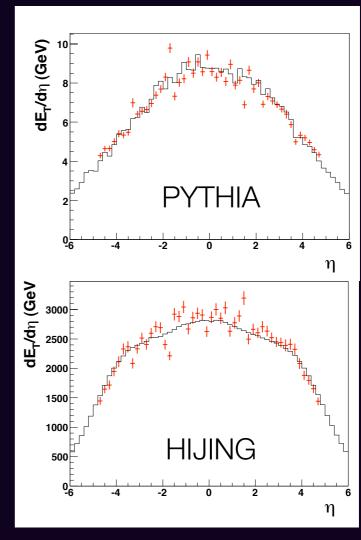


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Expect to test our techniques on jets and photons



ATLAS HI Working Group

Substantial progress since last year

US group has written proposal for DOE

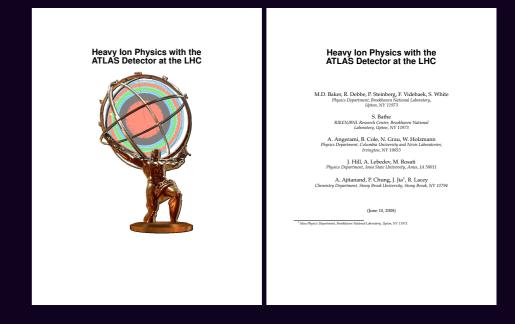
- submitted last week

Increased involvement from Russian groups

- IHEP, Moscow, Russia
- JINR, Dubna, Russia (workshop May 11-12, 2008)
- MePHI, Moscow, Russia

New groups ramping up

- Weizmann Institute, Israel
- Santa Maria University, Valparaiso, Chile
- University of Sao Paolo, Sao Paolo, Brazil.
- Pontificia Universidad Catolica de Chile, Santiago, Chile





Summary and Conclusions

 LHC is essential for continued progress in the study of QGP properties, via bulk observables and especially high p_T proceses

 Good progress on study of global variable, jets, photons and quarkonia with ATLAS

 Early p+p is essential to these studies, by establishing baseline reference data

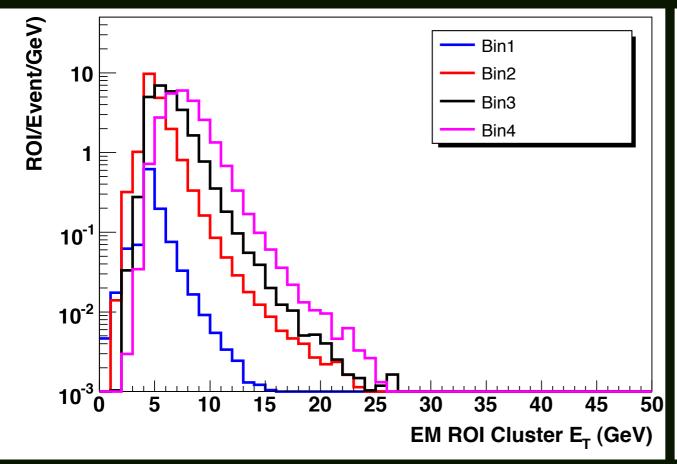
Members of heavy ion group have been contributing to minbias effort Will also contribute to jet and direct photon measurements

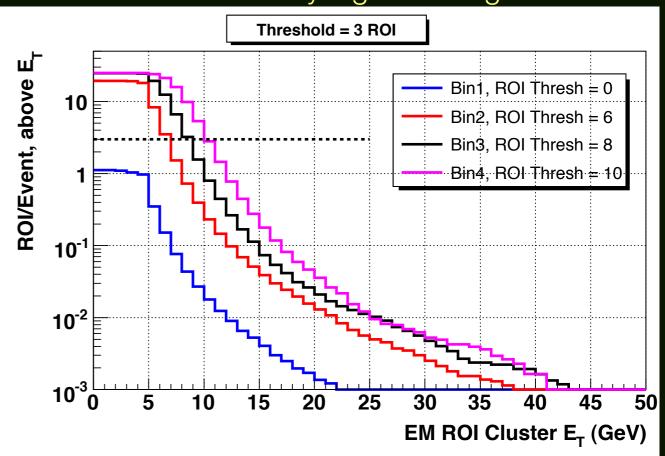




Triggering on Jets in P6+P6







From previous discussion, obvious that jet triggering is complicated by background fluctuations

Expected to choose background-dependent Rol thresholds to keep constant Rol/pevent



KT Jet Finding

